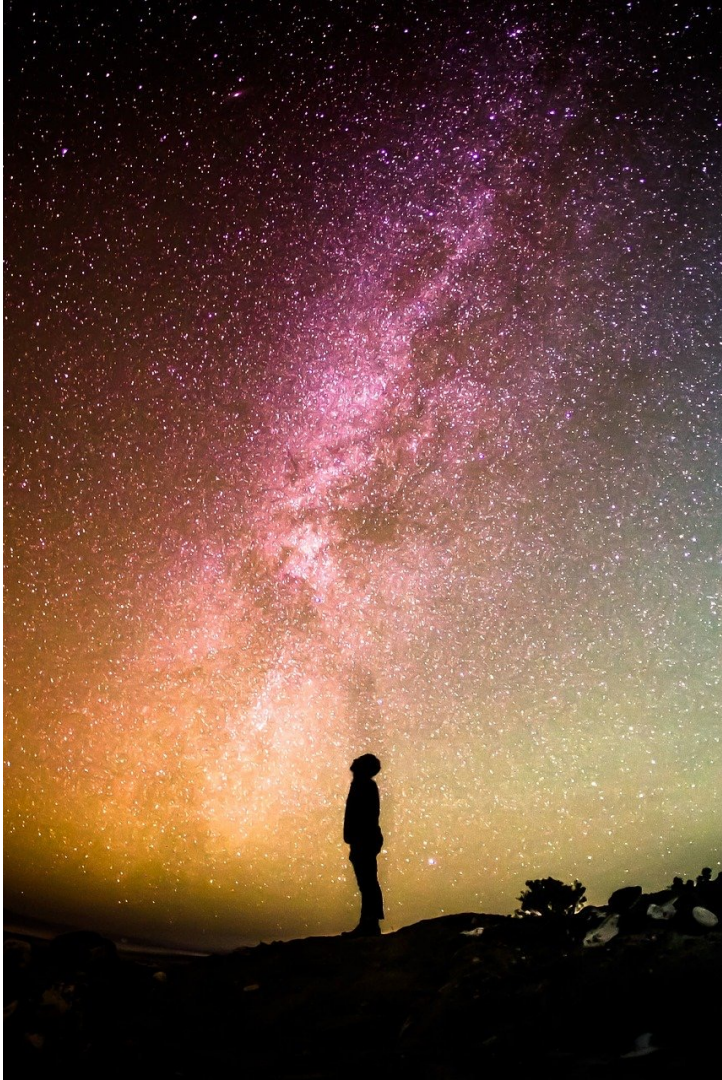
Lessons we can learn from historic astronomical discoveries

Speaker: Rui Luo (CSIRO Space and Astronomy)



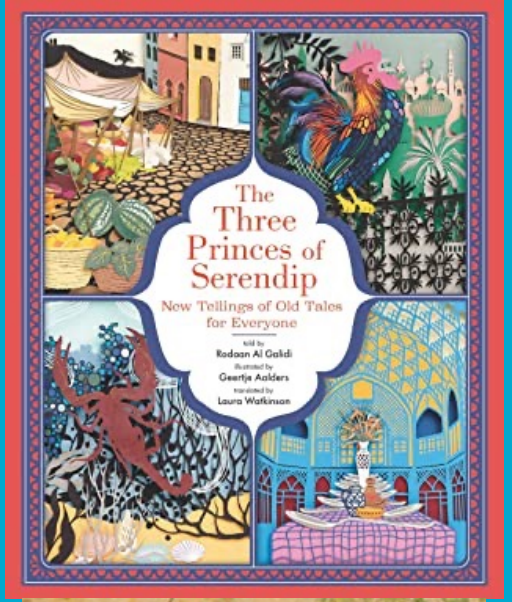
OUTLINE

- What is serendipity?
- History of astronomical discoveries
- Lessons from the history
- Challenges
- Outlook

What is serendipity?

- Definition: **An unplanned fortunate discovery**.
- Serendipity is a common occurrence throughout the history of sciences (Wikipedia)

- Etymology:
  - *Peregrinaggio di tre giovani figliuoli del re di Serendippo* – Michele Tramezzino, 1557
  - *The Three Princes of Serendip* – Horace Walpole, 1754



Serendipitous Life

- Life is like a box of chocolates. You never know what you're gonna get.

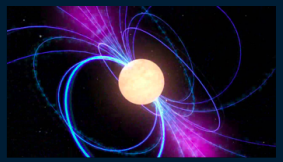
  — *Forrest Gump*

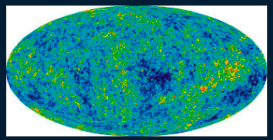
- Life is what happens to you while you're busy making other plans.

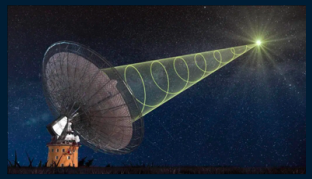
  — *Beautiful Boy* · John Lennon

Astronomical discoveries

- Historical unexpected discoveries: Cosmic Ray, Quasar, CMB, GRB, Pulsar, FRB, etc.



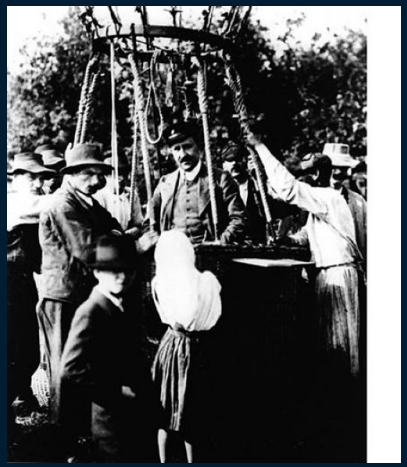




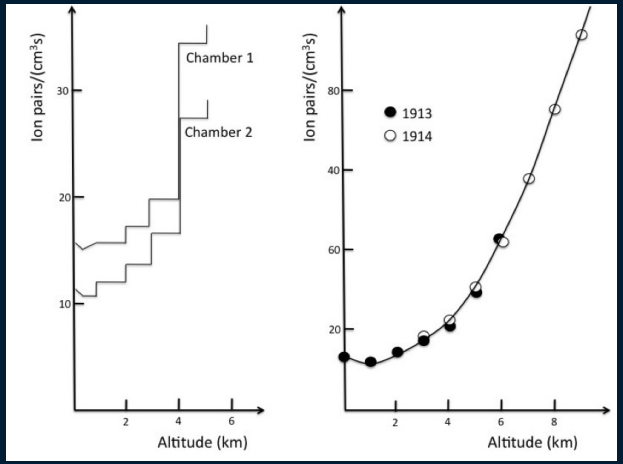
1910s 1960s 2000s

Cosmic Ray (1912)

- Original Intention: Investigating whether the atmospheric ionisation is caused by the terrestrial radioactive elements (such as Rn).
- Serendipity: Cosmic ray detection



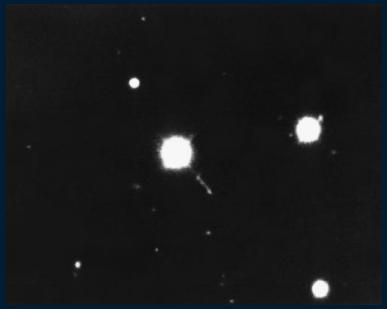
Balloon detector built by Victor Hess



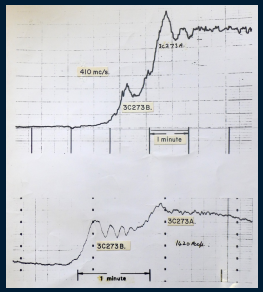
Ionisation curve measured in 1912-1914 (Credit: Wikipedia)

Quasar (1963)

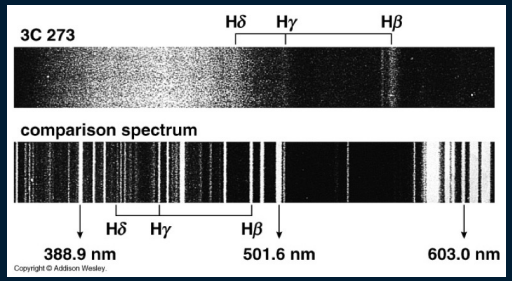
- Original Intention: Observing anomalous radio sources (point-like and variable)
- Serendipity: A redshifted quasi-stellar object (3C 273)



3C 273: image and spectrum
(Credits: Wikipedia)

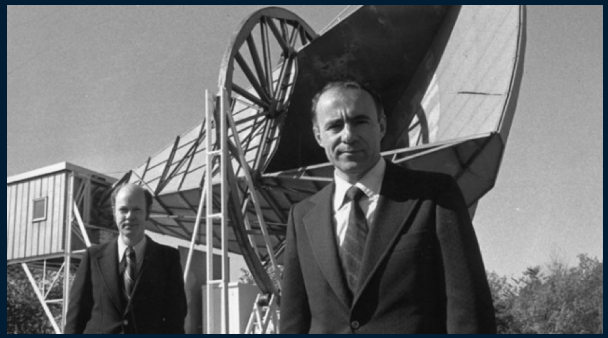


Credits: John Sarkissian (CSIRO-ATNF)

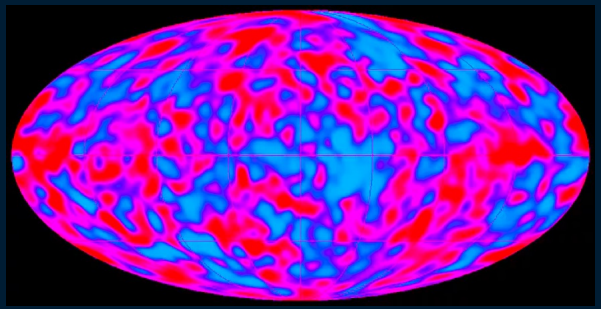


Cosmic Microwave Background (1964)

- Original Intention: Satellite communication experiments.
- Serendipity: Accidental discovery of 4.2 K antenna temperature excess in the background.



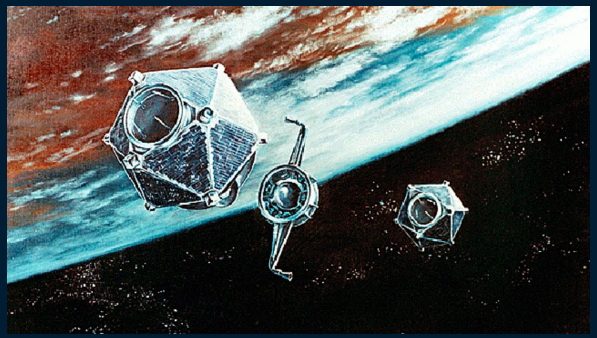
Penzias and Wilson at the Holmdel Horn Antenna (Credit: Wikipedia)



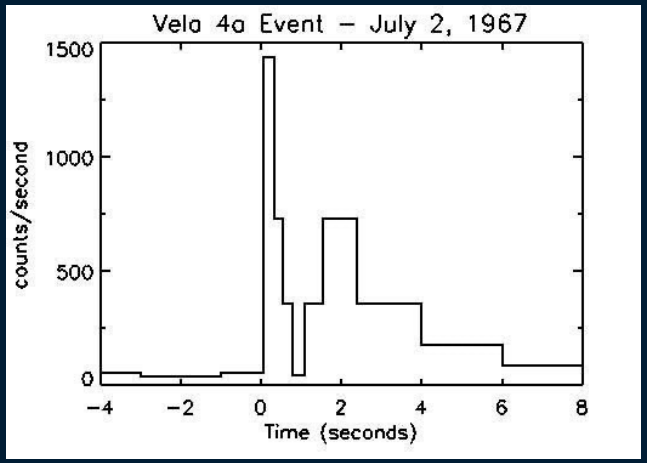
The CMB map by COBE satellite (Credit: NASA)

Gamma-ray Burst (1967.7)

- Original Intention: Monitoring nuclear tests by the Soviet Union.
- Serendipity: A rapid gamma-ray excess from distant space



Vela satellites (Credit: Wikipedia)

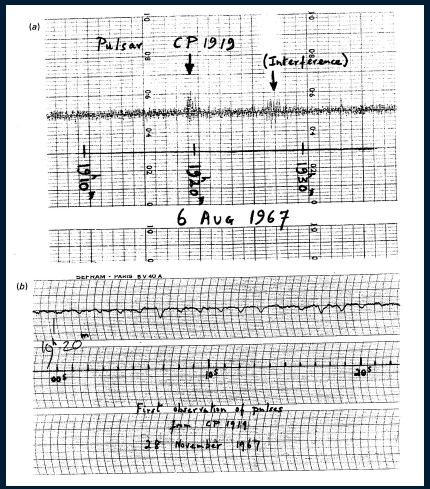


First GRB ever detected (Klebesadel et al. 1973)

Pulsar (1967.11)

- Original Intention: Observing for interplanetary scintillation of solar wind.
- Serendipity: A series of periodic pulses, “Little Green Man”.

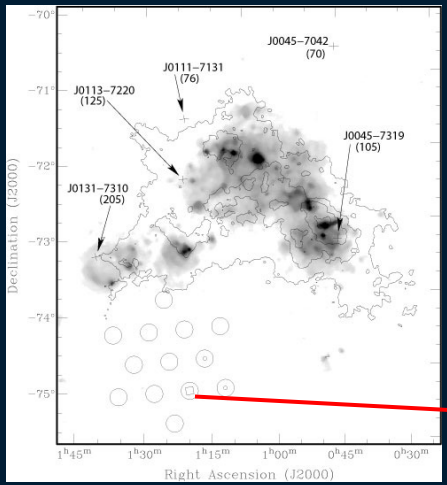
Joycelyn Bell Burnell at the Cambridge Interplanetary Scintillation Array (Credit: Joycelyn Bell Burnell)

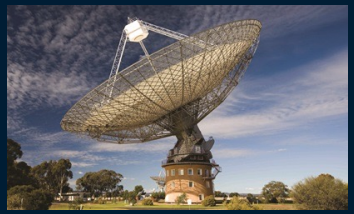


The pulsar CP1919 (Credit: Jocelyn Bell Burnbell and Antony Hewish)

Fast Radio Burst (2007)

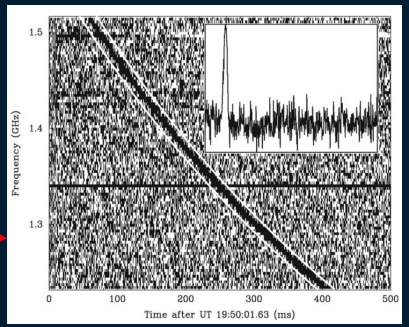
- Original Intention: Searching for pulsars in SMC with the Parkes “Murriyang” radio telescope.
- Serendipity: A bright highly-dispersed single pulse with extragalactic origin





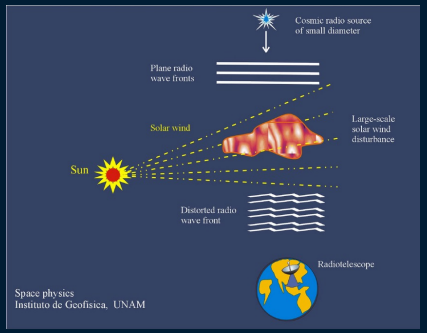
Duncan Lorimer and David Narkevic (Credit: WVU)

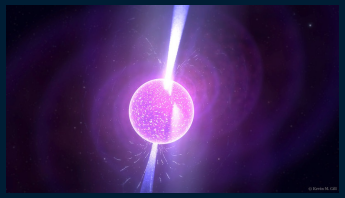
Lorimer et al. 2007

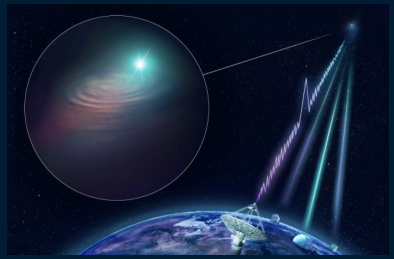


Next discovery?

Interplanetary scintillation → Pulsar → Fast Radio Burst → ?







How to make **serendipitous** discovery **deliberately**?

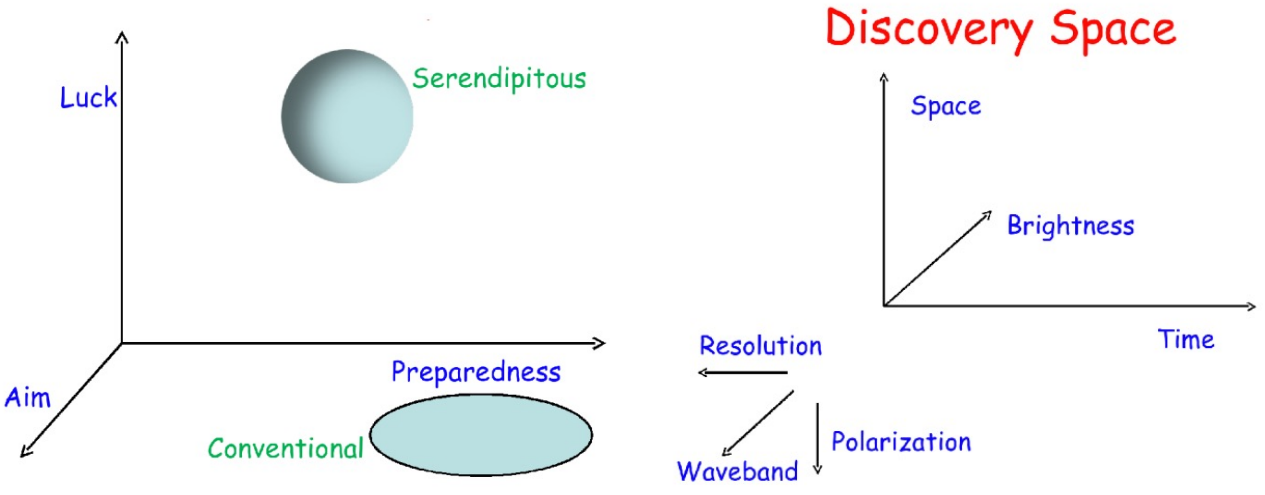
- Essence: Anomaly detection in parameter space

- Keys to finding the unknown unknowns
  - 1) Emerging facilities with innovative instrumentation -> Scope
  - 2) **New algorithms** to generalise the unknown stuff -> Methodology
  - 3) Higher performance computing in data reduction -> Dynamic
  - ……

- The other factor (uncontrollable): LUCK, LUCK and LUCK !!!

Serendipities in the discovery space

Fabian 2009

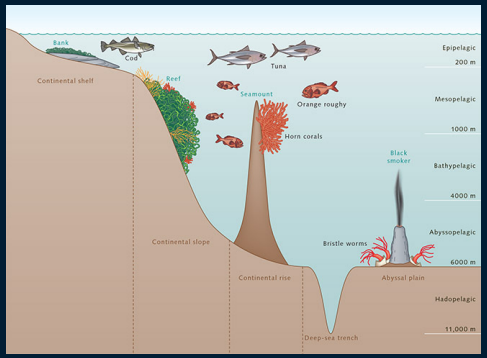


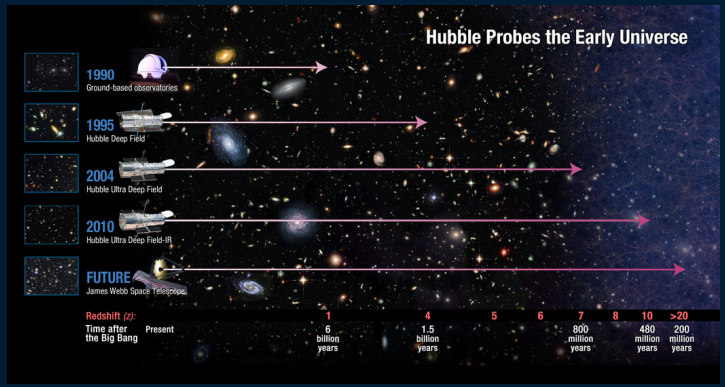
Luck is always indispensable!!!

Several Lessons

Lesson 1: Extending Parameter Space

- With parameter space extended, it's sooner or later people would find new stuff





- How to extend the observing scope in astronomy:
  - Building new telescopes and instruments
  - Using new observing windows: GWs, UHE neutrino, etc.
  - Increasing the searching area: e.g., de-dispersion range -> extragalactic FRB

Lesson 2: Searching for anomalies

- Quasar was discovered through selecting weird and anomalous variable radio sources.
- Finding odd stuff may indicate new objects we've never seen?

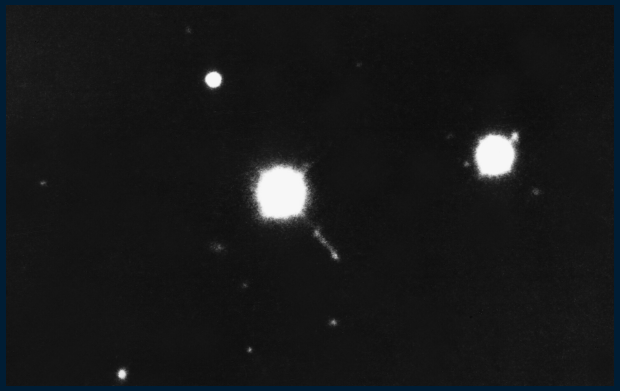
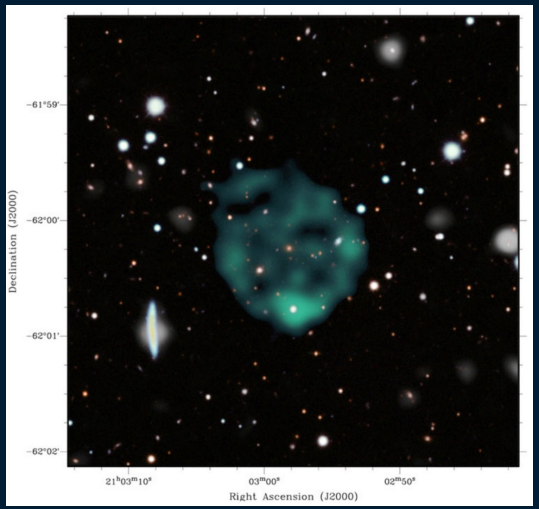


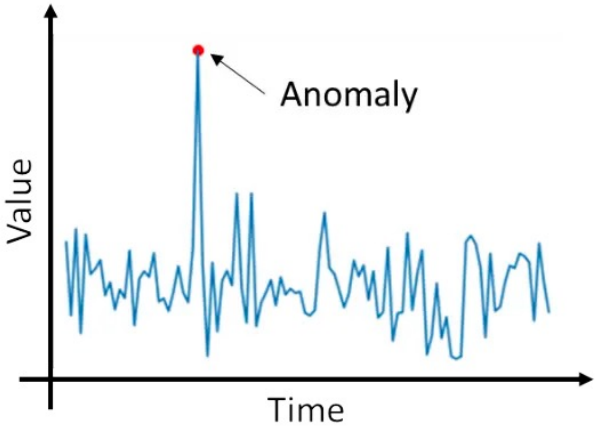
Image of 3C 273 (Credits: Wikipedia)

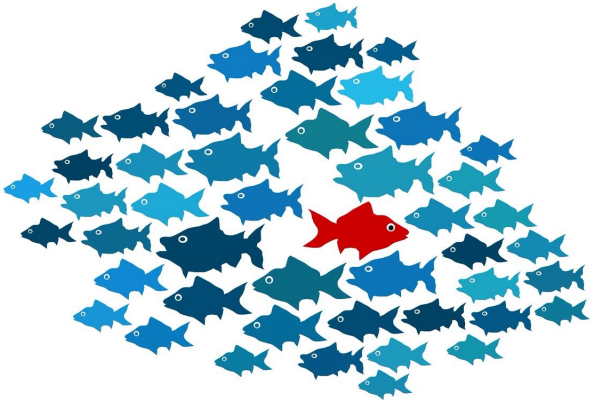


Norris et al. 2021

Challenges

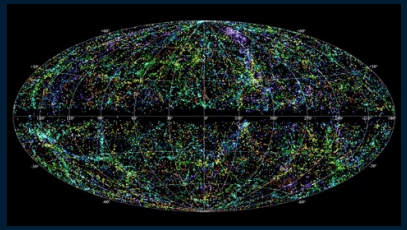
- On the algorithm for anomaly detection:
  - Matched filter ✗
  - More generalised algorithm ?

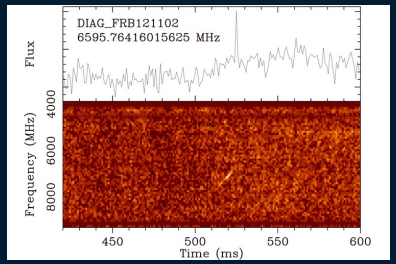




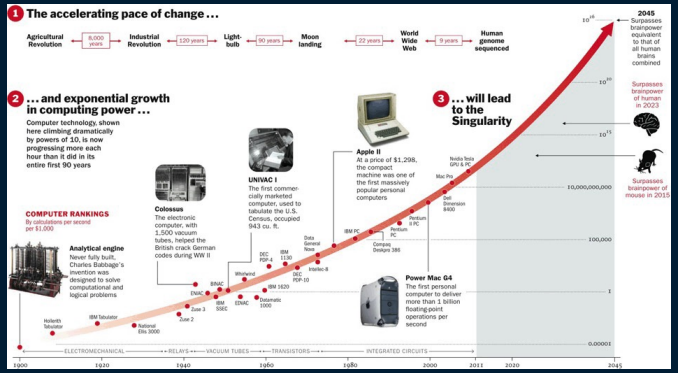
Lesson 3: Increasing compute power

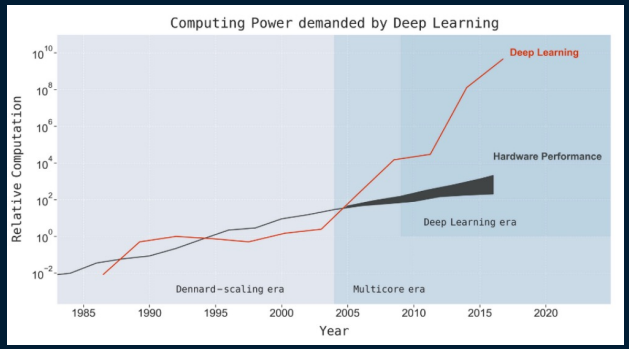
- Compute power determines how fast we can scan the observing scope.





- Computing is essential to deploying ML/AI.





Thompson et al. 2020

Lesson 4: Be prepared and open-mind

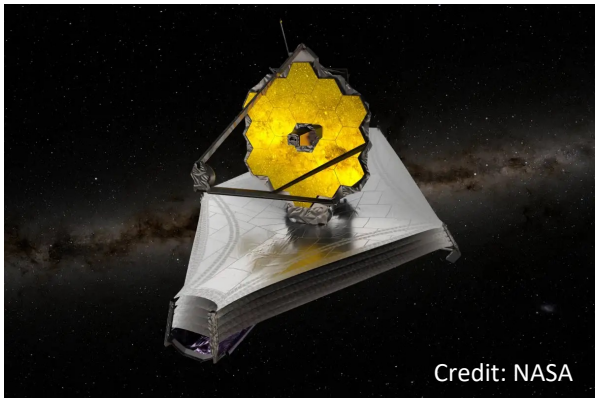
- Chance favours prepared mind
  - Discovery of FRB: Parkes 13-beam receiver
  - Discovery of GWs: LIGO's Interferometer
- Be open and generalised
  - Pulsar signals kept as a military secret for decades
  - Too much knowledge becomes problem: 3C 48 missed to be the first discovered quasar.
  - SETI: focused on extremely narrow-band signal
- Think Different
  - Brainstorming new ideas for anomaly detection

Think different

“The people who are crazy enough to think they can change the world are the ones who do.” — Steve Jobs

OUTLOOK

- New mega-science facilities are coming into being !!!
- Finding the unknown is becoming one of the most cutting-edge science field.
- It’s sooner or later we will make discoveries of new astronomical phenomena.



Thank you for listening

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